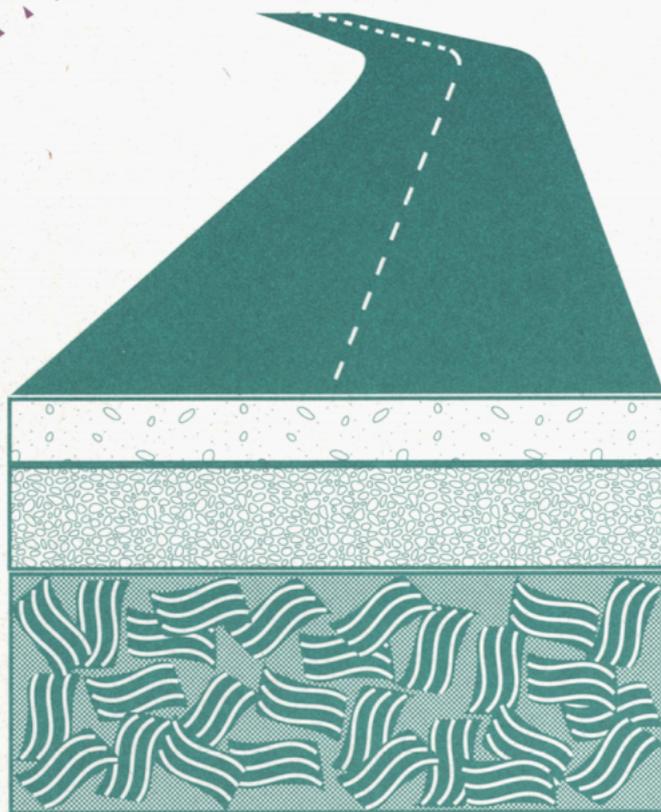




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Using Shredded Waste Tires as a
Lightweight Fill Material for Road
Subgrades

Research

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USING SHREDDED WASTE TIRES AS A LIGHTWEIGHT FILL MATERIAL FOR ROAD SUBGRADES

A Summary Report

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Executive Summary

Waste tires have been a disposal problem in the past and are continuing to accumulate throughout the U.S. today. Recent figures from the United States Environmental Protection Agency (EPA) show that over 279 million waste tires are being added annually to the estimated 2 billion tires currently stockpiled around the country. Waste tire stockpiles constitute environmental and health hazards by producing air pollution from tire stockpile fires and breeding grounds for potential disease carrying mosquitoes and vermin. Under recent environmental legislation that encourages the reuse or recycling of waste products in the US, the use of discarded tires has been increasing. The EPA estimated in 1990 that 11% of the waste tires generated in the U.S. annually were converted into energy and 7% were recycled into new products. In order to avoid even larger stockpiles across this country, alternate ways of using waste tires must be implemented.

The most desirable approach to reduce waste tire stockpiles is to recover the resource by recycling. However, tires are now being burned throughout the nation as a fuel source. Tire Derived Fuel (TDF) has also become popular in Minnesota where from 60 to 80 percent of the tires processed are used up by this method annually. It has been estimated that waste tires stockpiles will be eliminated in Minnesota by 1996, largely due to the processing of tires as TDF. A California plant's emissions have been deemed environmentally safe and all of the by-products from the combustion process are recyclable.

Using shredded waste tires as a lightweight fill material for road construction has proven to be another beneficial use of this waste product. Minnesota began using shredded tires as a lightweight fill material in 1985 on logging roads through areas with weak soils. Shredded tires were proven to be a viable form of lightweight fill because they are relatively lightweight, inexpensive, and non-biodegradable. In general, the material is very elastic, very porous, contains good vibration damping properties, and is easily compacted. On the downside, shredded tires lack set design standards and specifications.

Shredded tires have been used as a lightweight fill material in Minnesota, Colorado, Oregon, Washington, North Carolina, Virginia, and Wisconsin. In Minnesota there are over 24 sites that have used shredded tire fill, most of which were used on either private driveways, county roads, or city streets.

The long term environmental impacts of using shredded tires as fill material are still unknown. In 1989, the Minnesota Pollution Control Agency (MPCA) initiated a laboratory study which attempted to model several scenarios which could develop in the field. The tests submerged the tire shreds in solutions with pH levels varying from 3.5 to 8.0. Potentially harmful substances were found in the laboratory studies when tires were exposed to highly acidic solutions (pH 3.5). This led the MPCA to issue guidance concerning the use of shredded tires below the water table or in contact with groundwater. Wisconsin also conducted laboratory leachate studies on shredded tires, but did not find the leachates to be as harmful as Minnesota's tests indicated. However, both states do not currently recommend that shredded tire material be placed below the water table. Further environmental studies might lead to a more permissive policy on where waste tires may be used as a fill material. This in turn may allow millions of waste tires to be put to a viable engineering use and thereby alleviate the problem of waste tire disposal and the associated health and environmental hazards.

Measured pH's from 285 culvert sites throughout Minnesota ranged from 4.7 to 8.3 with average values ranging from 6.3 to 7.9 (20). Another study showed that the mean pH of rain ranged from 4.7 in northeastern Minnesota to 7.5 in the southwest corner of the state (21). With this wide variation in potential pH values it seems appropriate that testing of the existing soil and/or water be completed before construction of a shredded tire lightweight fill is proposed. This information should help the designer determine what mitigation measures are necessary to reduce potential environmental impacts. It may also lead to the development of less restrictive requirements for use of shredded tires as lightweight fill when the pH is neutral (near 7.0).

With this in mind Mn/DOT together with Mn/DNR and MPCA have decided to re-evaluate the laboratory study completed for the MPCA in 1989. The new study will attempt to review the actual impacts of shredded tires on the environment by conducting another laboratory study, using the bio-assay technique to get a handle on "real" environmental impacts, and monitoring a actual shredded tire fill site in the field. Hopefully, the information developed from this study will help us to use shredded tires in an efficient and environmentally safe manner.

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1. Introduction

Old abandoned tires from cars, trucks, farm and construction equipment and off-road vehicles are stockpiled throughout the country. In 1990, nearly two billion waste tires were estimated to be stockpiled across the United States. Today, that number is growing by more than 279 million annually (1). In Wisconsin, the DNR appraises their state's contribution at more than 20 million waste tires heaped at 500 to 600 sites throughout the state (2), while Minnesota generates four million tires annually (3).

Not only are these tire mounds eyesores, they are also environmental and health hazards. The little pools of water retained by whole waste tires create an ideal breeding ground for mosquitoes. Aside from the persistent annoyance, mosquitoes have been shown to spread various dangerous diseases (4). Equally hazardous are tire fires, which pollute the air with large quantities of carbon smoke, hydrocarbons and residue (2). These fires are virtually impossible to extinguish once started.

Currently, the only large scale methods to use waste tires are through burning for electric power generation, production of cement in cement kilns, energy to run pulp and paper mills, and recycling at tires-to-energy facilities. In 1990, the Environmental Protection Agency (EPA) estimated that out of the 242 million waste tires generated that year, 78% of the tires were either stockpiled, landfilled, or illegally dumped (4). While some states bury waste tires this is only a temporary solution because the tires, in many cases, tend to float back up to the surface. Landfilling waste tires has also become more and more expensive as landfill space has decreased (4). Some states, like Minnesota, have forbidden the disposal of waste tires in the land. However, tires are now being burned throughout the nation as a fuel source. Tire Derived Fuel (TDF) has also become popular in Minnesota where from 60 to 80 percent of the tires processed are used up by this method annually. It has been estimated that waste tires stockpiles will be eliminated in Minnesota by 1996, largely due to the processing of tires as TDF.

Section 1038 of the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) mandated the use of recycled rubber in bituminous pavements nationwide. The mandate requires every state to use recycled rubber in an amount equal to 5% of all federally funded projects in 1994, 10% in 1995, 15% in 1996 and 20% thereafter. Estimates on the quantity of recycled tires that will be used vary, but it should be substantial if various barriers are overcome. Potential problems with rubber modified asphalt pavements include, their ability to be recycled, their long term performance as a paving material, and environmental hazards (emissions). Due to some of these potential problems, a one year moratorium has been placed on the mandate by the federal government. Over the next year, the FHWA will study the various issues and make recommendations to Congress concerning the implementation of Section 1038.

1.1 Different Uses for Waste Tires

Over the years several new ways of beneficially using discarded waste tires have been developed. The EPA estimated in 1990 that 11% of the waste tires generated annually in the U.S. were converted into energy; while 7% were recycled into new products and 5% were exported out of the U.S (4). Using waste tires as a fuel source, TDF, is one way of putting waste tires to good use. Near San Francisco, the Modesto Power Plant produces energy by burning close to 5 million tires a year. The plant's emissions have been deemed environmentally safe and all of the by-products from the combustion process are recyclable (4). A power plant in Connecticut also burns tires as a fuel source at a rate of 10 million per year. Minnesota reported that 5.5 million tires, or 60% of the tires processed in 1992, were used as TDF.

Another method of using waste tires is recycling the tires into new products. This includes reconditioning and reusing tires, grinding tires into rubber powder or distilling out the tires byproducts (pyrolysis) for reuse in new rubber products, and using waste tires as construction materials. This latter concept includes using whole, shredded, ground up, or baled tires for sound walls, retaining walls, windbreaks, reefs and breakwaters, erosion control devices, impact barriers, bituminous add-mixtures for road surfaces, road subgrades, and bases. This report will concentrate on the use of shredded tires as a lightweight fill material for road subgrades.

2. Shredded Tires as Lightweight Fill

In 1985, Minnesota's waste tires were piling up at record rates with few effective ways of disposal. At the same time, the Minnesota Department of Natural Resources (MnDNR) needed a more economical way to build logging roads to cross poor soils in state forests. One waste tire company suggested a solution to both problems. They proposed using waste tires as road construction materials, specifically as a lightweight fill material (5). The lightweight fill would serve to "float" the road section over the poor soils. While a state law prohibited the burial of waste tires, these tires would not be considered waste if used they were utilized as a raw road building material. With permission from the Minnesota Pollution Control Agency (MPCA), the company and the MnDNR proceeded to design and construct test sections on a northern Minnesota logging road using whole, partial and shredded tires (5). To date, this test road and many others around the state have performed well. Shredded tires, due to their ease of installation, have been the most widely used form of waste tires as a road subbase material.

2.1 Advantages of Shredded Tires

Shredded tires exhibit many advantages as a lightweight fill material. To begin with, shredded tires are non-biodegradable either above or below the water line under normal conditions. This provides for a stable road base for a longer time period than some other lightweight fill materials. Wood products like sawdust, bark, and wood chips tend to biodegrade over time if not completely submerged (5). In addition, shredded tires weigh only 20 - 40 pounds per cubic foot (320 - 640 kg per cubic meter). Because of their low density, tire shreds can be used to build roads over unstable soils. They are also easily transported and placed on the job site and display excellent porosity features (5). This is important for proper drainage of highway base grades. Given current rates of use, the existing stockpiles of waste tires will not be depleted any time soon. This supply should help to keep the material costs down for some time. Additionally, using shredded tires as fill material will help to free up other valuable road building resources, namely sand and gravel for other use (2).

From an economic viewpoint, tire shreds present even more advantages. First of all, shredded tires are relatively inexpensive. In Minnesota, tire shreds vary in cost from \$1.25 to \$3.25 per cubic yard (\$1.63 to \$4.45 per cubic meter) delivered to the job site, according to a local supplier. This cost may also be subsidized by the state in order to clean up tire dump sites. Foamed or cellular concrete and polystyrene, two other forms of lightweight fill, have very high unit costs. For example, cellular concrete has a unit cost of \$40 to \$45 per cubic yard (\$52 to \$59 per cubic meter) (6). In addition, the use of shredded tires may also help complete a job faster and therefore save more money. For

example, construction projects utilizing surcharging methods often have waiting periods of four to twelve months for the surcharge materials to settle and compress the unstable soils. Under similar conditions, lightweight fill designs do not generally require a waiting period (7). This may also reduce the time and inconvenience associated with staged construction projects.

2.2 Disadvantages of Shredded Tires

While shredded tires appear to be an excellent choice for a lightweight fill material, they do have some drawbacks. First, because the use of shredded tires as a lightweight fill material is a fairly new concept, there is a definite lack of information concerning their use and very limited design standards are available (2). Recent projects have used trial and error methods for determining the amount and depth of shredded tires to use. One report does not recommend shredded tires for use under hard surfaced pavements unless a substantial overburden thickness is used, 5 foot (1.5 m) minimum (19).

Second, waste tires do require some preparation before they can be used as a road building material. The tires must be cleaned so that they are free from oils and grease in order to avoid soil and groundwater contamination. In addition, the Minnesota Pollution Control Agency (MPCA) has shown that tire shreds may leach out heavy metals when subject to highly acidic solutions with a pH of 3.5 (8). These conditions are unlikely to be found in most wetlands and peat bogs, locations where lightweight fill materials are most useful. However, testing should be completed on a site-by-site basis if any doubt exists.

Finally, to the general public it may appear that using shredded tires for fill material is just another way of burying waste. The public may oppose projects using waste tires even if projects are deemed environmentally safe. Overall, more research must be conducted on the engineering and environmental aspects of this "new" material in order for it to have an impact as an alternative construction material.

2.3 Engineering Properties

Shredded waste tires have many beneficial engineering properties as a lightweight fill material. To begin with, compacted shredded tire material is more porous than a washed gravel (5). CalTrans conducted a constant head permeability test on two types of shredded tires and the permeability coefficients were on the order of 10,000 ft/day (3,000 m/day)(19). When used in the road base or subbase, shredded tires will improve drainage below the pavement and therefore should extend the life of the roadway. Additionally, tire shreds are very elastic. This property enables the tire material to better distribute the roadway loads over unstable soils (5). However, the same elastic

properties can lead to higher than normal deflections (19). Shredded tires also possess vibration damping properties, a benefit in situations where vibratory compaction is hazardous to the surroundings. Furthermore, shredded tires are easily compacted and consolidated. Their angular shape and excellent friction characteristics allow the individual tire shreds to lock together very well (5). Lastly, shredded tires have bulk densities comparable to wood chips, approximately 20 pounds per cubic foot (320 kg per cubic meter) (5). Compacted densities are about 40 pcf (640 kg per cubic meter).

Although there are no widely accepted design standards for shredded tires, construction contracts have produced some similar specifications for tire shreds as a lightweight fill material. First of all, the size of the tire shreds is always specified. Different shredding processes can produce shredded tires with highly varying characteristics. The source of the tires i.e., automobile, truck, tractor, etc. may also complicate the situation. A maximum size shred or chip along with a specification for percent passing a certain size screen is usually given. For example, 80% of the material (by weight) shall pass a 6 inch (15 cm) screen. Additionally, it is usually stated that the tire chips shall be free of oil, grease, or any other contaminants that may leach into the soil or ground water. If any metal fragments are present in the tire shreds, they must be firmly attached and 98% embedded to the material. No metal fragments are to be allowed in the fill material unless they are embedded within the tire shreds. Specifications also frequently state that all shredded tire pieces shall have at least one sidewall severed from the face of the tire. Finally, the weight (by truck measure) of the shredded tire material is normally specified (7).

3. Shredded Tire Fill Sites

Even though the concept of using shredded waste tires for lightweight fill is a fairly new idea, it has been used in other countries around the world. In Gothenburg, Sweden, shredded tires have been used as a lightweight fill material in a municipal street subgrade and may be used in the future as a fill material for a noise reduction embankment. Eddy Ismael, Chief of the Geotechnical Bureau for City of Gothenburg, states that the tire material provides a reduction in settlements on the local clay subsoil (the shredded tires have 1/4 the density of a regular fill material) and also help the environment by reducing the amount of tires that need to be stockpiled (9).

In the U.S., several other states have made productive use of this waste product. The largest use of waste tires as a structural fill was completed in the Summer of 1993 near Williamsburg, Virginia. Two 600 foot (182 m) long ramp embankments up to 20 feet (6.1 m) high were constructed out of a mixture of 2.2 million shredded tires and sandy soil. The Colorado Division of Highways has recently completed an Interstate highway construction project near Denver utilizing shredded tires as a lightweight fill material. In addition, the Wisconsin DOT has built a road test section to study the engineering and environmental properties of waste tires incorporated into road construction. The Oregon DOT and the FHWA sponsored a project using shredded tire fill on a 300 ft (91 m) slide prone section of a state highway near Camas Valley. The North Carolina DOT recently used 5000 cubic yards (3800 cubic meters) of shredded tires mixed with soil in a road subbase as part of a large study which incorporated solid waste materials and recycled products into the construction of a four lane state highway. And, in Goldendale, Washington, the Klickitat County Public Works Department has constructed gravel road test sections using shredded tires for the purpose of determining just how much cover is needed over shredded tires to support pavements. Because all of the above mentioned projects have been completed in the past few years, there is little performance data available.

3.1 Minnesota (Figure 1)

Through February, 1992, the Minnesota Pollution Control Agency (MPCA) has documented 23 sites in Minnesota which have used over 80,000 cubic yards (61,000 cubic yards) of shredded tires or approximately 2.2 million tires. Over half of these projects are privately owned driveways and roads while four are city and township roads, three are county roads, and two are DNR Forest roads. A few of the projects used shredded or whole tires for purposes other than as a road subgrade. One project in downtown Minneapolis used the lightweight tire shreds as a fill material to support a park and landscaping above an underground parking lot. Another site used the tire material as a lightweight fill over an existing watermain. A third project incorporated whole tires for use as an erosion control method in a fly ash pond (10). The following case studies are examples of some of the projects completed throughout Minnesota to date.

Case Study Locations

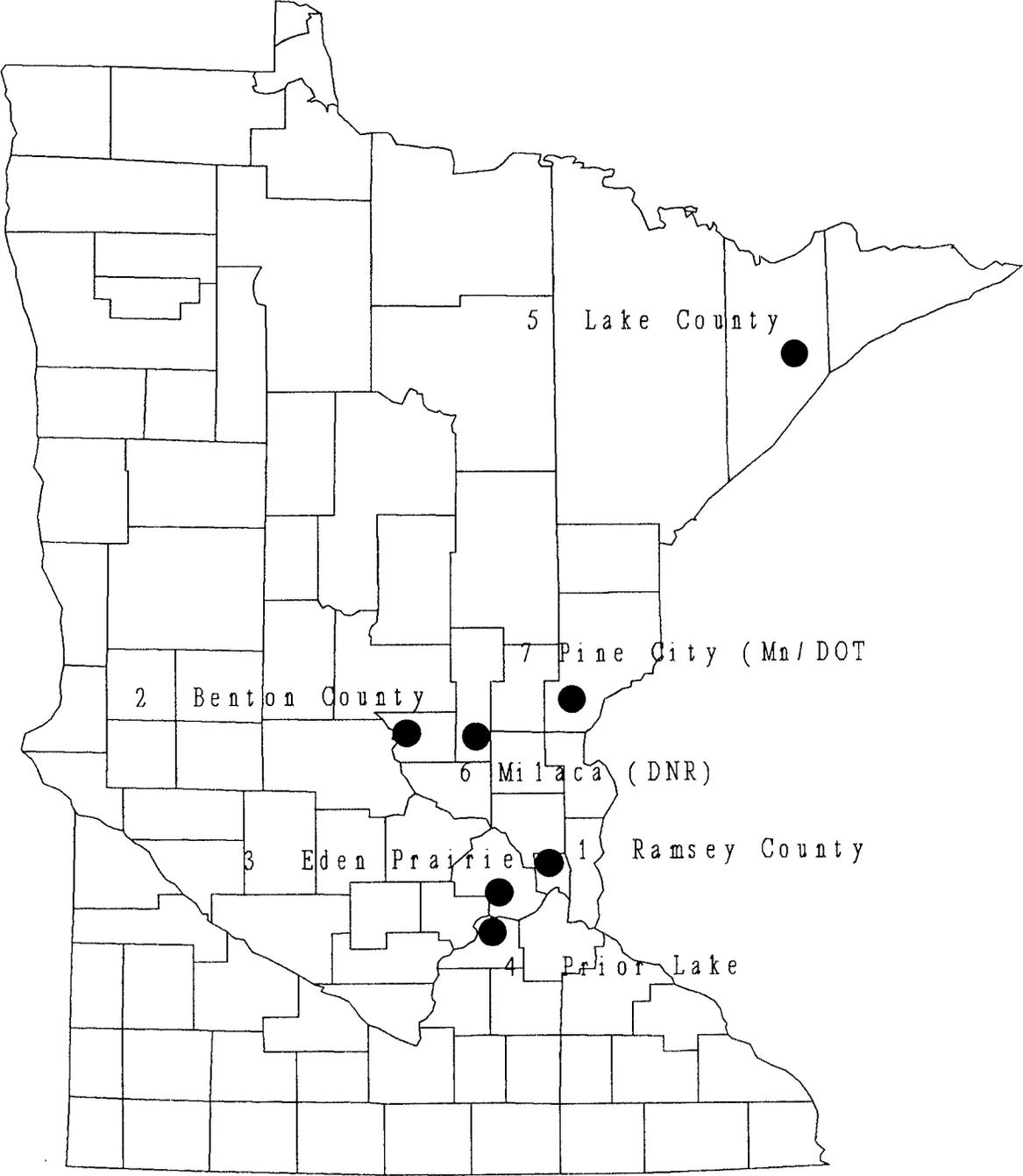


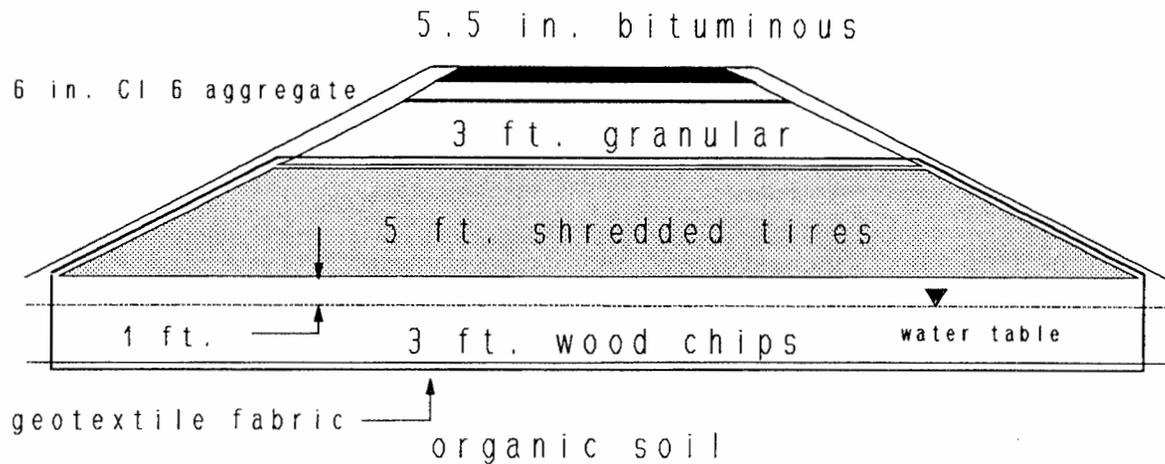
Figure 1

3.11 Case Study 1: Ramsey County, MN (Figure 2) (11)

One location where shredded tires were used as a lightweight fill material is in Ramsey County, near St. Paul, Minnesota. Here a stretch of Ramsey County Road 59, also known as Centerville Rd., runs over a mucky, low lying area with a very high water table. Over the years, this roadway section experienced excessive settlements and in 1990 required reconstruction. It was determined that simply surcharging the affected area in order to stabilize the organic soils would not work because the weight of the sand would cause an underground shear failure. It was determined that some form of lightweight fill was needed. The county proceeded to hire a consulting engineering firm and a geotechnical subconsultant, to design the 300 foot (91 m) section of roadway. An economic and engineering analysis resulted in the selection of shredded waste tires as the lightweight fill material.

Construction began in the winter of 1990. The first step involved removing the existing soils to five feet (1.5 m) below the original roadway elevation and placing geotextile fabric on the bottom and sides of the excavation. Next, three feet (0.9 m) of wood chips were deposited on top of the geotextile fabric to a depth of one foot (0.3 m) above the water table. This procedure was required by the Minnesota Pollution Control Agency in order to ensure that the tires would not be within the saturated zone. Approximately 4,725 cubic yards (3,600 cubic meters) of shredded tires were then deposited on top of the wood chips and compacted to a depth of 3 feet (0.9 m) above the original roadway elevation. The 3 inch by 3 inch (7.6 cm by 7.6 cm) tire shreds were compacted with a dozer. The top layer of geotextile fabric was then sewn to the initial layer of fabric in order to fully encapsulate the wood chips and tires. Next, three feet (0.9 m) of granular material was placed over the fabric and graded to the final subgrade elevation. The final two layers consist of 6 inches (15 cm) of Class 6 aggregate (a granular base material) and 5.5 inches (14 cm) of bituminous base and wear course.

The performance of the shredded tires at this site has varied. The embankment has failed on the east side resulting in extensive cracking and some settlement of the pavement for approximately 75 feet (23 m) near the centerline. The cause of the failure can be attributed to a shear failure of the poor underlying soils and is not related to the use of the lightweight fill. Two other areas within this project have also failed because of the poor soils. Conventional design methods (i.e. remove and replace) were used in these areas in an attempt to prevent foundation problems.



Case Study 1 - Ramsey County

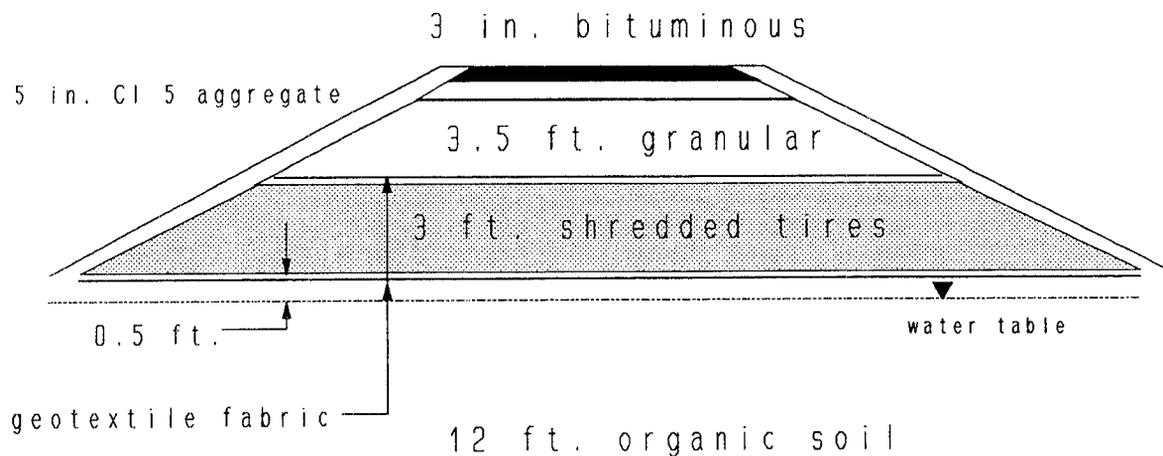
Figure 2

In the summer of 1992 a separate 1000 foot (305 m) long section of this project was constructed with shredded tires used as a lightweight fill. Two feet of (0.6 m) shredded tires were placed beneath 3 feet (0.9 m) of granular fill. The tires were again encapsulated with geotextile fabric. The final two layers consist of 6 inches (15 cm) of Class 6 aggregate and 5.5 inches (14 cm) of bituminous base and wear course. This section is performing well with no cracking or excessive settlements apparent to date.

3.12 Case Study 2: Benton County, MN (Figure 3)

Near Rice, Minnesota, there is a section of Benton County State Aid Highway 21 that has been designed to "float" over the existing soil. The two lane highway was originally constructed with sand and gravel subbase and was performing well. Problems started when the surrounding water levels increased to the elevation of the roadway surface. An attempt to raise the roadway with conventional granular fill overloaded the underlying 12 feet (3.7 m) of peat and muck and caused an embankment failure (12). The county subsequently hired a consultant to review options to correct the soil stability problem. After performing a cost/benefit analysis, the county decided to use shredded tires as a lightweight fill material (13).

Reconstruction on the 250 foot (76 m) section began in the fall of 1989. The first step was to excavate down to a point one-half a foot above the swamp/marsh level. Next, a geotextile fabric was sewn together and positioned at the bottom of the excavation. Following the fabric, approximately 52,000 shredded tires were deposited in 2 foot (0.6 m) lifts to a level 3.5 feet (1.1 m) below the top of the subgrade elevation. Each tire shred was no more than 8 inches (20 cm) square or round and no longer than 12 inches (30 cm) in length. The shredded tire material was then compacted and overlaid with another geotextile fabric layer. The next step placed granular backfill over the fabric and compacted the fill with ordinary compaction. Finally, the gravel base and subbase was replaced and the roadway was allowed to settle naturally for several months (12). The bituminous surface was constructed the following spring.



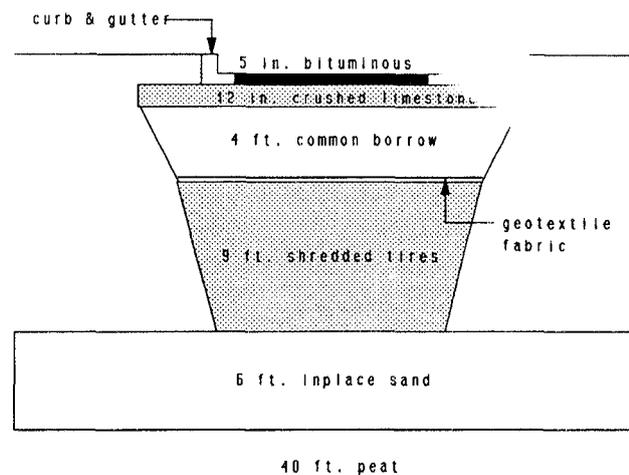
Case Study 2 - Benton County
Figure 3

To date, the county road has experienced some distress. There is moderate longitudinal cracking in the wheel paths that appears to be fatigue related. Some rutting was also observed. There is also a longitudinal crack (slightly bowed) which could point to a slope failure. Settlements do not appear to be significant at this time.

3.13 Case Study 3: Eden Prairie, MN (Figure 4) (5)

In Eden Prairie, Minnesota a road embankment project for a municipal 9 ton roadway incorporated shredded tires in order to solve a settlement problem. The original roadbed fill, placed over a swamp containing 40 feet (12 m) of soft organic soils, failed during construction due to subsidence of the soft organic soils. Three years after the construction of the project, the road bed was still settling an average of one foot per year. When development of the properties along the road was proposed, the city decided to correct the problem. It was decided that shredded tires, used as a lightweight fill material, would be used in the solution to the settlement problem.

The construction began by removing 10-14 feet (3.0-4.3 m) of the in-place road bed soils. Next, approximately 4,100 cubic yards (3,100 cubic meters) of shredded tires were placed in 2 - 3 foot (0.6 - 0.9 m) lifts. The tire shreds were 6 - 8 inches (15 - 20 cm) wide and 12 - 24 inches (30 - 61 cm) long and were compacted by a D-8 dozer to a density of 40 - 45 pounds per cubic foot (640-720 kg per cubic meter). A geotextile



Case Study 3 - Eden Prairie
Figure 4

fabric was then positioned on top of the tire shreds. Following the fabric, 4 feet (1.2 m) of common borrow was deposited and compacted to standard density. After waiting three weeks to allow the shredded material to settle, 12 inches (30 cm) of crushed limestone was placed over the fill material followed by 3.5 inches (8.9 cm) of bituminous wearing course. The bituminous wearing course was paved the following spring.

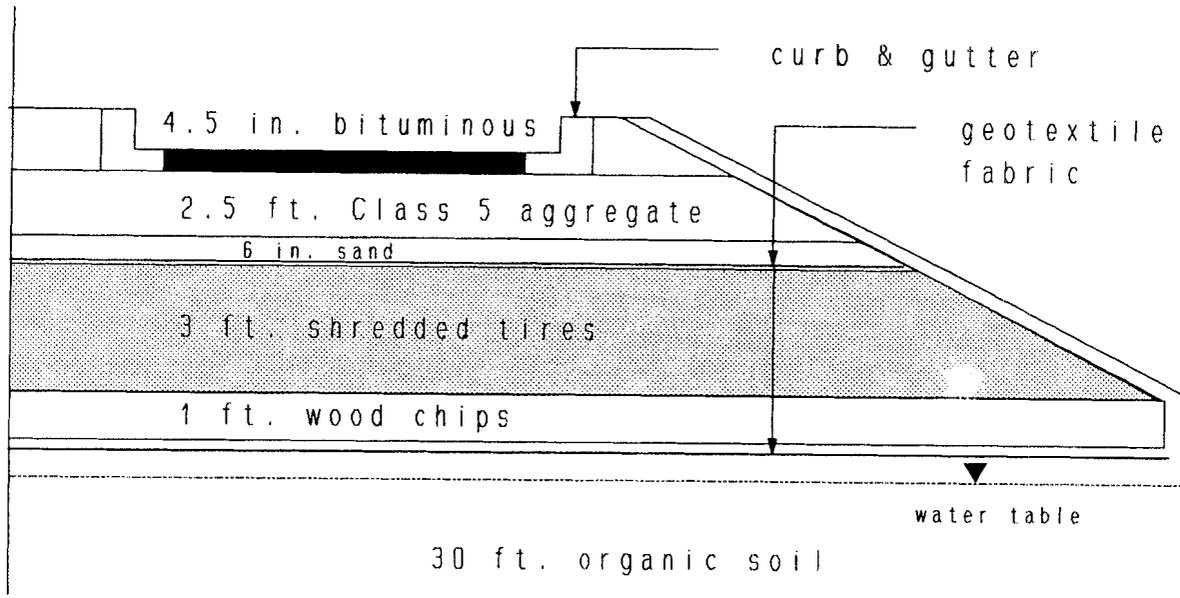
Settlement data, gathered from settlement plates placed at both the bottom and the top of the shredded tires, revealed that the fill has performed very well. Over a 19 month period, the roadway has settled an average of 0.9 inches (2.3 cm) a year while the subcut at the bottom of the tires has settled only an average of 0.4 inches (1.0 cm) a year. The pavement has performed well to date with no noticeable problems.

3.14 Case Study 4: Prior Lake, MN (Figure 5) (7)

In Prior Lake, Minnesota a city street intersection required reconstruction in 1991. A new alignment put the intersection of Duluth and Tower Avenues over a wetland area with 30 feet (9.1 m) of organic deposits. Three options were analyzed in an attempt to solve the problem of stabilizing the poor soils. The first option, removing the estimated 30 feet (9.1 m) of organic material and replacing it with granular material, was ruled out because of the high cost. The second option, surcharging the poor soils with granular material in order to compress the organics, was dismissed because it would have required between 1 and 1-1/2 years to complete. The remaining option, using a lightweight fill material, was selected because of its lower cost and shorter construction period.

The subgrade construction began by placing geotextile fabric (Mn/DOT Type 3) directly over the wetland. Next, wood chips were deposited to an elevation of one foot (0.3 m) above the expected water table level to meet the MPCA guidelines. Approximately 3 feet (0.9 m) of shredded tires, totalling about 9,600 cubic yards (7,300 cubic meters), were then graded over the woodchips. The 4 inch (10 cm) tire shreds were easily graded and compacted with dozers and loaders. Next, a second blanket of geotextile fabric (Mn/DOT Type 5) was placed over the tire shreds followed by 6 inches (15 cm) of sand subbase. The final layer of subgrade, consisting of 2 feet (0.6 m) of Class 5 granular base, caused an unexpected settlement of 6 inches (15 cm) on the subgrade. An additional 6 inches (15 cm) of base was added in order to correct the grade. The design engineers felt that this settlement further increased the elastic modulus of the shredded tire material.

Several field tests were used to analyze the performance of the lightweight fill materials. Settlement plate data revealed that after the initial 6 inch (15 cm) settlement the embankment stabilized and settled very little. A plate load test applied directly on top of the shredded tires revealed that the tire material was very compressible and displayed a very low elastic modulus. After reviewing all of the testing data, the design engineers recommended that an R-value of 5 should be assumed for pavement designs incorporating shredded tire subgrades. The third test, a Falling Weight Deflectometer (FWD) test, produced data that was difficult to evaluate due to the unconventional road section. To date, the city street has not experienced any significant settlements and the bituminous surface is performing well.



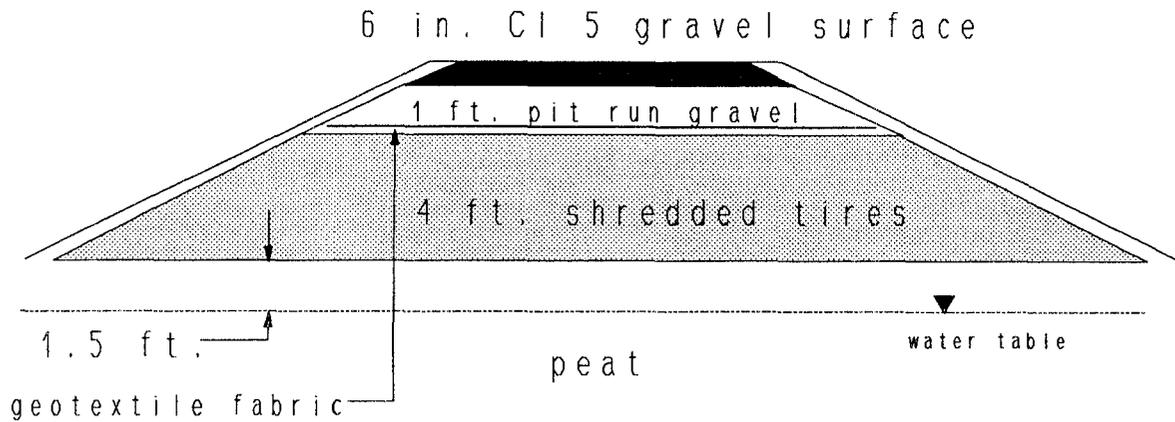
Case Study 4 - Prior Lake

Figure 5

3.15 Case Study 5: Lake County, MN (Figure 6) (14)

Near Finland, Minnesota, the Lake County Highway Department reconstructed a gravel road section on County State Aid Highway 7 using 3,900 cubic yards (3,000 cubic meters) of shredded waste tires. The road section, located at a bridge approach, was originally built over very unstable soils (peat) and experienced excessive settlements annually. In an attempt to stabilize the roadway, the county tried using a corduroy method where logs are placed transversely across the roadway. This technique was unsuccessful in solving the settlement problem. In 1990, the county decided to reconstruct the road segment using a lightweight fill material. After reviewing the available options, the county selected shredded tires because of their low cost and durability (non-biodegradable).

The road was reconstructed over the existing grade with a 4 foot (1.2 m) layer of shredded tires and capped with a layer of geotextile fabric. Pit run gravel was then placed to a depth of approximately 1 foot (0.3 m) and topped off with about 6 inches (15 cm) of Class 5 aggregate. The



Case Study 5 - Lake County

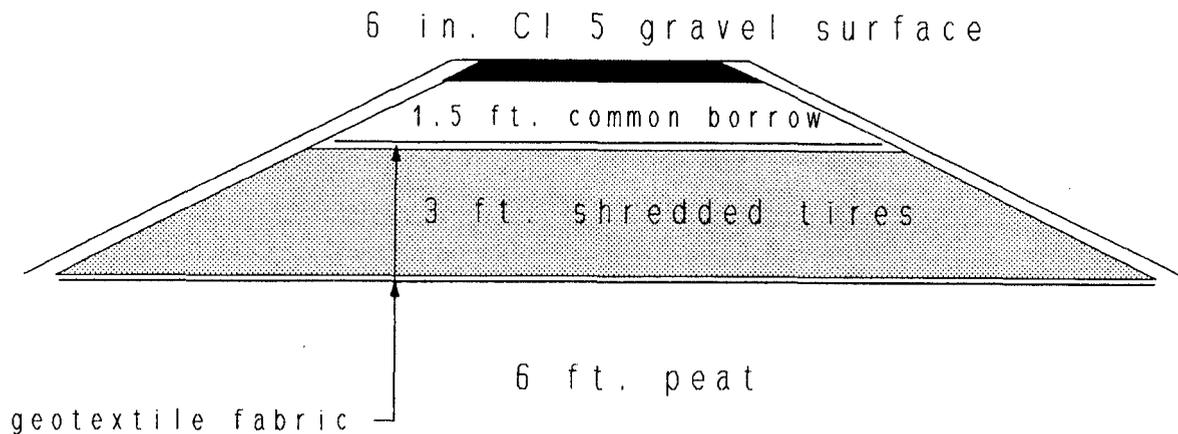
Figure 6

tire shreds were quite large, ranging in size from 4 x 12 inches (10 X 30 cm) up to 1/4 of a whole tire. Compaction was completed with a dozer. In compliance with MPCA standards, the shredded tire layer was located at an elevation between one and two feet (0.3 - 0.6 m) above the water table. To date, the county reports no noticeable settlements on the road segment.

3.16 Case Study 6: Milaca, MN (Figure 7) (5)

Near Milaca, Minnesota there is a 200 foot (61 m) section of gravel road using shredded tires for subgrade support. The road, known as the Esker Trail, is owned by the Minnesota Department of Natural Resources and provides access to a sand and gravel pit. A lightweight tire fill was utilized here to cross a section of wetland containing unstable peaty soils.

The fill section included a layer of geotextile fabric, followed by a 3 foot (0.9 m) layer containing 3,000 cubic yards of shredded tires. A second layer of geotextile fabric, followed by 1.5 feet (0.46 m) of common borrow (mineral fill), capped with 6 inches (15 cm) of gravel completed the section. The embankment was constructed and stabilized in less than a week and settlement testing revealed that the settlements experienced from the tire fill were 40 to 50% less than what would have been expected from mineral fill.



Case Study 6 - Milaca, Mn.

Figure 7

3.17 Case Study 7: Pine City, MN (Figure 8) (18)

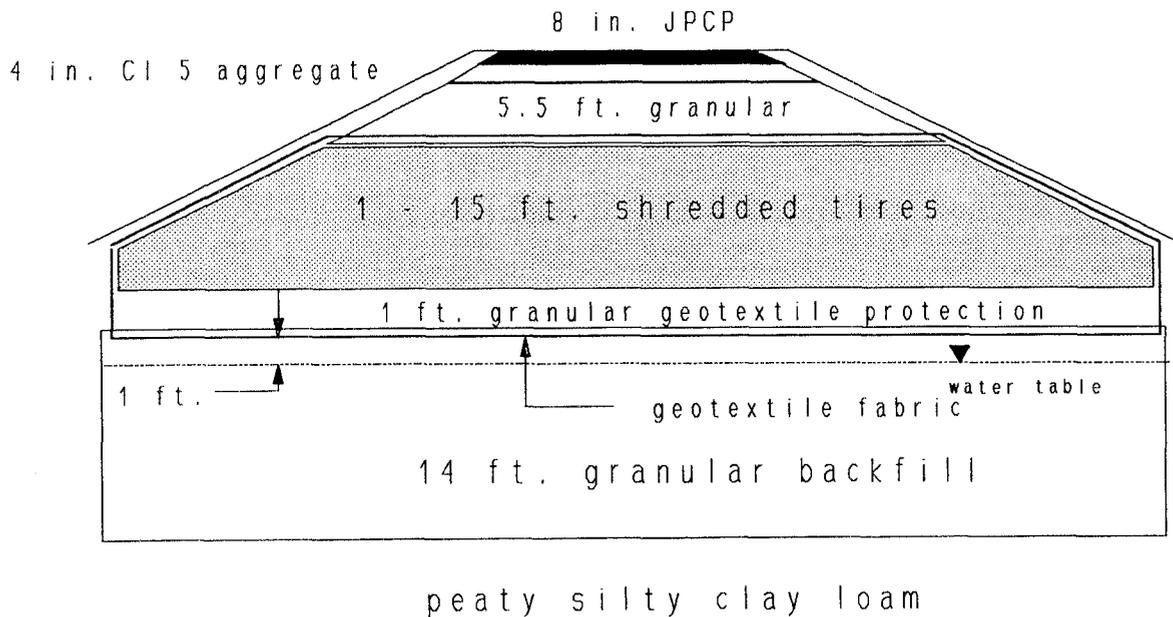
Near Pine City, Minnesota, approximately 30,000 cubic yards (23,000 cubic meters) or about 900,000 shredded tires were used to construct a 1000 foot (300 m) section of an Interstate freeway exit ramp embankment. The project, designed by the Minnesota Department of Transportation (Mn/DOT), is located in the NW quadrant at the intersection of C.S.A.H. 11 and I-35. The tires were used to provide lightweight fill over a trapped layer of peaty, silty clay loam after a conventional fill material had caused a slope failure. The embankment has a maximum width of 150 feet (46 m), a variable shredded tire thickness of 1 to 15 feet (0.3 to 4.6 m) and 3:1 (H:V) side slopes. The shredded tires were placed at a unit cost of \$1.20/yd³ (\$1.5 /m³). The specification for the shredded tires included the following:

1. 90% of the material (by weight) must pass an 8 inch (20 cm) screen. Eight inches (20 cm) shall be the maximum desired dimension.
2. A minimum of 50% of the material (by weight) must be retained on the 4 inch (10 cm) screen.
3. All pieces shall have at least one of the sidewalls removed.
4. All metal shall be 95% embedded in the tire pieces. No free metal fragments shall be allowed in the fill.

5. The shredded tires shall weigh less than 600 pounds per cubic yard, (360 kg/m³) loose volume.

6. A representative sample shall be submitted to the Project Engineer for approval before delivery.

Construction of the shredded tire embankment began in the fall of 1992 with the placement of geotextile fabric and a one foot (0.3 m) thick granular layer. The shredded tires were then placed and compacted with a dozer to a maximum height of 15 feet (4.6 m). Construction was completed in August of 1993 and included the addition of another geotextile layer and about 6 feet (1.8 m) of granular material. It took about 4 feet of granular fill to provide for a stable enough surface for equipment to operate on. The road surface was 8 inch (20 cm) thick doweled, jointed plain concrete. No performance problems have occurred on this section to date.



Case Study 7 - Mn/DOT, Pine City, MN

Figure 8

Two additional shredded tire projects will be constructed by Mn/DOT. One project involves minor embankment widening over peat deposits near Fosston, MN on TH 2. The second project is still in the design phase but will likely include in excess of 100,000 cubic yards (76,000 cubic meters) of shredded tires placed to a maximum height of 20 feet (6 m). The tires will be used to construct an Interstate freeway ramp and loop on TH 212 in Eden Prairie, MN. This project will consume approximately 3,000,000 tires, which shows the potential of such an application to absorb large numbers of tires.

4. Environmental Studies

When tire fill road projects were first proposed, very little was known about the potential environmental impacts of buried waste tires used as a road base material. Environmental agencies set up studies and tests to model the effects rubber tires might have in the soil and groundwater environments. From previous testing it was known that waste tires did not biodegrade either in or out of the water, however, environmentalists wanted to see if the tire material would produce leachates under certain conditions.

4.1 Leachate Studies

4.11 Minnesota

In 1989, the Minnesota Pollution Control Agency (MPCA) contracted with a consultant to perform laboratory studies to discern the compounds, if any, that may leach from waste tires samples and distinguish those that were detrimental to the environment. The MPCA wanted to expose the samples to a variety of potential leaching environments including the most severe possible in order to better understand possible environmental impacts. In addition, soil and groundwater samples taken from two existing shredded tire fill sites and a stockpile site were to be analyzed and compared with the lab tests. The tire samples were collected from a Minnesota tire dump and were cut into pieces and placed in pH solutions ranging from 3.5 to 8.0. The results of the study were revealed in a report entitled "Waste Tires in Sub-grade Road Beds" published by the MPCA in February, 1990 (8). The following points summarize the findings of the study.

1. Metals are leached from tire materials in the highest concentrations under acid conditions. Laboratory studies indicate barium, cadmium, chromium, lead, selenium and zinc are constituents of concern.
2. Polynuclear Aromatic Hydrocarbons (PAHs) and Total Petroleum Hydrocarbons (418.1) are leached from tire materials in the highest concentrations under basic conditions. Constituents of concern included List 1 (carcinogenic) and List 2 (non-carcinogenic) PAHs.

3. Tire shreds did not leach contaminants of concern in neutral solutions (pH 7.0).
4. Drinking water Recommended Allowable Limits (RALs) may be exceeded under "worst-case" conditions for certain parameters. Parameters include barium, cadmium, chromium, lead, selenium, zinc, List 1 (carcinogenic) and List 2 (non-carcinogenic) PAHs.
5. Co-disposal limits and E.P. Toxicity limits are generally not exceeded for the parameters of concern.
6. Asphalt samples also tested in the lab leached metals in concentrations exceeding RALs in all pH solutions.
7. Field studies and the biological survey did not identify significant differences between waste tire areas and control areas for soil samples.
8. Water samples taken from field studies showed that RALs were exceeded for concentrations of four metals at one of the road fill sites while the other two sites met all RALs.

The range of pH solutions used makes this a relatively severe test on the acidic end. Measured pH's from 285 culvert sites throughout Minnesota ranged from 4.7 to 8.3 with average values ranging from 6.3 to 7.9 (20). Another study showed that the mean pH of rain ranged from 4.7 in northeastern Minnesota to 5.3 in the southwest corner of the state (21). It also states that "pure" rain, that is rain that is unaffected by any pollutants, is slightly acidic (pH 5.6-5.7), because it combines with carbon dioxide, a gas naturally present in the atmosphere.

4.12 Wisconsin

The Wisconsin Department of Natural Resources (WI/DNR) has also examined the environmental aspects of using waste tires as a highway fill material. In 1989, the State Laboratory of Hygiene (LOH) was asked to perform leachate tests on tire shreds. Robert Grefe, of the WI/DNR, reviewed the results of the study and summarized that shredded tires did not display any signs of being a hazardous waste. He noted that shredded tire samples leached minimal amounts of elements compared to other wastes and these elements were possibly originating from the surface coating of the tire material because their concentrations decreased after further leaching. (The MPCA report (8) also reported that newer tires appear to contain slightly higher concentrations of

leachable PAH compounds than older tires.) The concentration of the elements were determined not to be harmful to groundwater of surface water, however, Grefe suggests that because of the minor amounts of metal substances and indicators leached from the tires they are best used when placed out of the water (15).

In addition to the lab study, the University of Wisconsin conducted field studies on a shredded tire fill test section near Madison. Here, water quality samples were taken and compared to background samples from the same area. The results of the tests showed that most of parameters stayed within acceptable limits although manganese had a fairly high concentration (16). The researchers theorized that this could have been the result of the local geological formations because this higher level of manganese also was present in the background samples (16).

4.2 MPCA Guidelines

In 1990, based on the results of the leachate study (8), the Minnesota Pollution Control Agency (MPCA) developed guidelines for using shredded tires as a lightweight fill material in construction. These guidelines allow for the use of shredded tires in road repair and construction projects in Minnesota as long as 1) the waste material was situated above the water table and out of contact with ground water and; 2) the road surface is designed and built to provide for adequate surface drainage in order to avoid water seepage through the road surface and the tire material subbase. For general construction, the MPCA recommended a synthetic geotextile fabric be placed above and below the shredded tire material to keep the material together and to prevent the surrounding materials from migrating into the lightweight fill. In addition, a low permeability material must be placed over the tire shreds to prevent the intrusion of surface water for all construction projects. Furthermore, every proposed project must show that there is an engineering need for the waste tire material (i.e. as a lightweight fill material). This is to ensure that the tires are put to a beneficial use and not simply used as a landfill (17).

5. Conclusion

In the U.S. today, over 2 billion waste tires are currently stockpiled around the country. According to the U.S. E.P.A, nearly eight out of every ten of the 279 million tires discarded annually in this country are either stockpiled, landfilled, or illegally dumped. In an attempt to alleviate this problem, many states have discovered beneficial uses for waste tires including burning tires for energy and recycling tires into new products.

Shredded tires have been used for lightweight fill in sites around the United States and in other countries. States that currently have shredded tire fill sites include Minnesota, Wisconsin, Oregon, Washington, North Carolina and Colorado. Minnesota has more than 23 sites throughout the state. In 1985, the State of Minnesota began using waste tires as a lightweight fill material for roads over unstable soils on an experimental basis. Over the years these waste tires, primarily shredded tires, have proven to exhibit many positive characteristics as a lightweight fill material. Shredded tires are very lightweight, non biodegradable, relatively inexpensive, and very porous. Some of the disadvantages of shredded tires include a lack of engineering design standards, the unknown long- term environmental effects, and possible negative public opinion to their use.

Minnesota has completed some testing on the environmental effects of waste tires used as road building materials. In 1990, the Minnesota Pollution Control Agency (MPCA) sponsored leachate and water quality testing of this material. The results of the lab study concluded that some harmful elements may be leached when the tires are exposed to highly acidic solutions. This led the MPCA to develop guidelines governing the use of shredded tires, allowing the waste tire material to be used in unsaturated conditions only. The State of Wisconsin also conducted laboratory studies on shredded tire material and found that shredded tires leach minimal amounts of detrimental substances compared to other wastes.

The potential environmental effects of using shredded tires as a lightweight fill material are currently related to the leaching action of water. The study (8) used to determine the MPCA guidelines subjected the waste tires to solutions ranging from a pH of 3.5 to 8.0. The solutions were considered highly acidic and highly basic respectively, especially in the natural environment. Past testing on the pH of backfill and drainage area soil at 285 culvert installations throughout Minnesota by Mn/DOT (20) has shown a range of pH from 4.7 in the northeast section of the state to 8.3 in the far west portion. Average pH ranged from 6.3 to 7.9. With this wide variation in potential pH values it seems appropriate that testing of the existing soil and/or water be completed before construction of a shredded tire lightweight fill is proposed. This information should help the designer determine what mitigation measures are necessary to reduce potential environmental impacts. It may also lead to the development of less restrictive requirements for use of shredded tires as lightweight fill when the pH is neutral (near 7.0).

5.1 Reasons for Further Studies

Further engineering and environmental studies are needed to develop waste tires into a efficient road building material. Studies are also needed because the demand for lightweight fill materials is increasing. For example, in the Minneapolis-St. Paul Metropolitan area, much of the land with stable soils has been developed leaving the only available areas with unstable soils that require creative engineering design in order to support loads (5). Shredded tires may prove to be an economic solution to this engineering problem if they are found to be safe under various environmental conditions.

One of the main disadvantages of using shredded tires as a lightweight fill material is that currently there are no set engineering design standards. Specifically, more work needs to be done in the area of overburden requirements. Current design requirements for the thickness and type of material used between the shredded tires and the pavement needs more refinement. Deflection of the shredded tires is a real concern. A recent report on the subject (19) recommends that "Shredded tires cannot be used under hard surfaced pavements, unless a substantial overburden thickness is used."

Finally, an increasing number of states have or are passing laws prohibiting the landfilling of waste tires. In order to avoid even larger stockpiles across this country, alternate ways of using waste tires must be implemented. Further studies might lead to a more liberal policy on where waste tires may be used as a fill material. This in turn may allow millions of waste tires to be put to good use and thereby alleviate the problem of waste tire disposal and the associated health and environmental hazards.

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